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Recent advances in reconstructive oral and maxillofacial surgery

By

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Certification of the Supervisor

I certify that this project entitled "Recent advances in oral and maxillofacial surgery" was prepared by the fifth-year student Hawraa Ghalib under my supervision at the College of Dentistry/University of Baghdad in partial fulfilment of the graduation requirements for the Bachelor Degree in Dentistry.

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microsurgical anastomosis	(MA)
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free fibula flap	(FFF)
polyetheretherketone	(PEEK)
additive manufacturing	(AM)
patient-specific implants	(PSI)

INTRODUCTION

Why we do reconstruction?

It is multidisciplinary approach used to repair significant oral and maxillofacial (OMF) abnormalities caused by tumors, trauma, or congenital disease **(Ghantous Y, Nashef A, Mohanna A, Abu-El-Naaj I, 2020).**

The physical and psychosocial consequences of disfiguring the face as a result of trauma, tumor removal, infectious illnesses, or congenital defects It can range from distorted self-image and low self-esteem to social disengagement, which can lead to chronic stress and depression, as well as suicidal thoughts **(Mao JJ, Stosich MS, Moioli EK, Lee CH, Fu SY, Bastian B, Eisig SB, Zemnick C, Ascherman J, Wu J, Rohde C, Ahn J,2010)**

As a result, reconstructive surgeons face a difficult task in restoring facial deformities. Patients have a great desire for a fully functional and aesthetically pleasing repair that does not modify their premorbid identity **(Hofer S, Mureau M, 2009).**

The main goals of reconstruction:

Specifically, complex functional, anatomic, and aesthetic qualities must be restored **(McGue CM, Mañón VA, Viet CT, 2021)**.

In considering any defect for reconstruction, three questions should be considered:

1. What is missing?
2. Where am I going to find the replacement tissue?
3. How am I going to get it there and hide most of the subsequent scars? **(Kaufman, A., J.2017)**.

1.1.Biomaterials used in reconstruction

Bone grafts materials are transplantable materials that can be placed in a bony defect to aid in the reconstruction and healing of the bone. Bone graft was first established in the 1800s **(N.M. Al-Namnam, Soher Nagi Jayash, 2019).**

No single biomaterial is optimum for every craniomaxillofacial application. Instead, surgeons should consider the advantages and disadvantages of each alternative in a given clinical situation, and select the material with lowest overall cost and morbidity, and the highest likelihood of success **(Rogers GF, Greene AK, 2012).**

In general, materials for bone replacement or augmentation fall into 3 categories:

1) Organic,

2) Synthetic organic,

3) And inorganic.

Organic substances include autograft (from the same individual), allograft (from another individual), and xenograft (from another species). Synthetic organics include hydroxyapatite and osteoinductive biologics such as bone morphogenic protein.Examples of inorganic substances are methylmethacrylate, silicone, porous polyethylene, titanium mesh, and bioactive glass **(Rogers GF, Greene AK.,2012)**

1.1.1.Autograft bone

Autograft bone is referred to bone which is harvested from one site and transplanted to another part of the recipient's body. It provides the three essential components that are necessary to generate and maintain bone: scaffolding for growth factors for osteoinduction, osteoconduction, and progenitor cells for osteogenesis **(KUBO et al., 2004)**.

Depending on the harvested site, it may be cortical or cancellous. The revascularization of the cancellous grafts occurs in approximately 2 weeks, while cortical might take two months or more to revascularize. Cancellous bone has a higher percentage of cells; thereby has more osteogenic potential. Conversely, cortical bone has fewer cells. However, it has higher levels of Bone morphogenic proteins (BMP's), and is useful when immediate framework or 3D augmentation is needed **(Zipfel et al., 2003).**

The most versatile bone graft reserve is the iliac crest. It is subcutaneous and easy to harvest in prone, lateral, supine or other positions. It is expendable and has a vast reserve of cancellous and cortical bone.
Other sites commonly used for autograft are tibia and fibula
The most common sites harvested intra-orally are around the surgical site,

ascending ramus, chin, and tuberosity **(Darby et al., 2008)**.

Advantages Autogenous bone remains the standard graft for stimulating bone healing and for filling bone defects. Superior osteogenic capacity, rapid incorporation, lack of disease transmission and union with a lack of immunologic deliberations makes autograft ideal **(Del Fabbro et al., 2005).**

Disadvantages amount of bone tissue that can be harvested from autograft are restricted, weakening of donor bone, donor site morbidity, increased blood **(Del Fabbro et al., 2005).**

1.2.COMMONLY USED MICROVASCULAR FREE FLAPS

1.2.1RADIAL FOREARM FLAP

The radial forearm free flap (RFFF) was developed in 1978 as a fasciocutaneous flap in the People's Republic of China. Since the introduction of the radial forearm flap by Yang et al in 1981, it has become the most frequently used free flap in head and neck reconstruction **(Yadav SK, Shrestha S, 2017)**.

It is commonly used for tongue, floor of mouth, lip and hard or soft palate reconstruction. Its greatest advantage is the thin and pliable nature of the flap ideal for the restoration of oral mucosal defects after ablative oncologic surgery. Its ease of harvest and long pedicle (about 20 cm) with large caliber vessels makes it popular with beginners **(Yadav SK, Shrestha S, 2017)**.

Other advantages are the presence of large diameter superficial veins (cephalic or basilica) and deep venous system (the venae comitantes).
Studies have shown that the smaller venae comitantes give reliable venous outflow but due to their smaller caliber, microsurgical anastomosis (MA) is difficult compared to the cephalic vein **(Yadav SK, Shrestha S, 2017)**.

One of the most significant drawbacks of RFFF is donor site morbidity, which can be avoided by suprafascial dissection and avoiding paratenton exposure in situations of paratendon damage during flap harvest, resulting in tenting and pain at the donor site **(Chen CM, Lin GT, FuY C, ShiehTY, Huang IY, ShenY S et al., 2005)**.

Other drawbacks include the need to sacrifice a major forearm artery, the radial artery, which reduced feeling in the region supplied by the antebrachial cutaneous nerve, as well as hand stiffness, pain, and a significant donor site scar **(Rhemrev R, Rakhorst HA, Zuidam JM, Mureau MA, Hovius SE, Hofer SO.,2007)**.

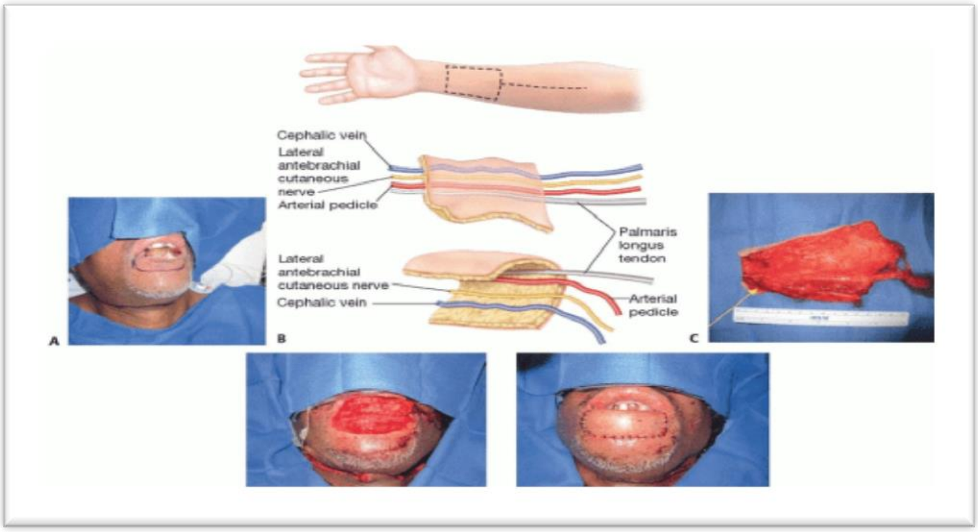

Figure 1: The radial forearm free flap (RFFF) used in lip reconstruction.

1.2.2ANTEROLATERAL THIGH FLAP (ALT)

The ALT was first described by Song et al in 1984, is supplied by perforating vessels arising from the descending branch of the lateral circumflex femoral artery, which arises from the profunda femoral trunk. It enjoys many advantages including low donor site morbidity, simultaneous harvest, large volume of skin and soft tissue available, a long pedicle, acceptability of site for the scar, ability to harvest as subcutaneous, fasciocutaneous, musculocutaneous or adipofacial flap thus giving multiple applications for this flap **(Yadav SK, Shrestha S, 2017)**.

The major problems with the ALT flap are the variations in the anatomy of the vascular pedicle, the difficult dissection technique, and the high incidence of hairy skin, especially in male. These led initially to a lack of popularity of this flap **(ValentiniV, CassoniA, MarianettiTM, BattistiA, TerenziV, Iannetti G., 2008)**.

Other disadvantages of ALT include lack of bone stock, since this is a pure soft tissue flap, difficult intramuscular dissection is necessary since it is a perforator flap, risk of morbidity when wider flaps are harvested with skin grafting and when vastus lateralis is harvested along with the flap **(Yadav SK, Shrestha S, 2017)**.

Despite of these disadvantages, the application of this skin flap has become increasingly widespread. ALT flaps have advantages and versatile designing capabilities that make them suitable for the reconstruction of OMF defects in most clinical settings **(Loreti A, Di Lella GU,Vetrano S,Tedaldi M, Dell’Osso A, Poladas G.Thinned, 2008)**.

Figure 2:ANTEROLATERAL THIGH FLAP (ALT)

1.2.3.FREE FIBULA FLAP

As its adaptation as a technique for manidbular reconstruction in 1989 by Hidalgo, the free fibula flap (FFF) is the first choice for restoration of extensive mandibular bone resection **(Yadav SK, Shrestha S, 2017)**.

The advantages of fibula include the length of bone available (around 25-30 cm), which permits multiple osteotomies and provides adequate pedicle length even for maxillary reconstruction. The peroneal artery and vein are usually of good quality and caliber and ideal for (MA) to the neck vessels. With proper harvesting techniques the donor site morbidity can be kept to a minimum. The lack of a large skin paddle is a drawback, which limits its use in situations with full thickness cheek defects along with a segmental mandibular defect with floor of mouth involvement. A method to overcome this problem is to use double flaps, like radial forearm free flap (RFFF) for soft tissue cover and fibula for hard tissue reconstruction of mandible and skin paddle of fibula used for the skin defect **(Yadav SK, Shrestha S, 2017)**.

Even though this is time consuming and technically difficult, these double flaps give excellent results. But the amount of cheek skin that can be replaced such is limited, also is the technical challenge of using two free flaps **(Bianchi B, Ferri A, Ferrari S, Copelli C, Poli T, Sesenna E. ,2008)**.

Figure 3: Harvest of a fibula composite flap for mandibular reconstruction.

1.2.4.ILIAC CREST

The initial reports involving transfer of vascularized iliac crest segments in 1978 were based off the superficial circumflex iliac artery. Taylor et al. in 1979 later proved that large amounts of vascularized iliac crest could be harvested when the flap was based off the deep circumflex iliac artery (DCIA) **(Yadav SK, Shrestha S, 2017)**.

The vascularized iliac crest free flap has various advantages for mandibular reconstruction, according to proponents, including the availability of strong, durable bone with an intrinsic curve that can help restore hemi-mandibular abnormalities **(Takushima A, Harii K, Asato H, Momosawa A, Okazaki M, Nakatsuka T., 2005).**

Additionally, the cortical bone of the iliac crest allows for dental rehabilitation via osseointegrated dental implants. There are several disadvantages to this flap that has caused it to fall out of favor in some centers. Major drawbacks include functional donor site morbidities. Major complications such as femoral neuropathy, contour deformity and incisional hernia formation were infrequent unless associated with the inclusion of a skin paddle **(Yadav SK, Shrestha S, 2017)**.

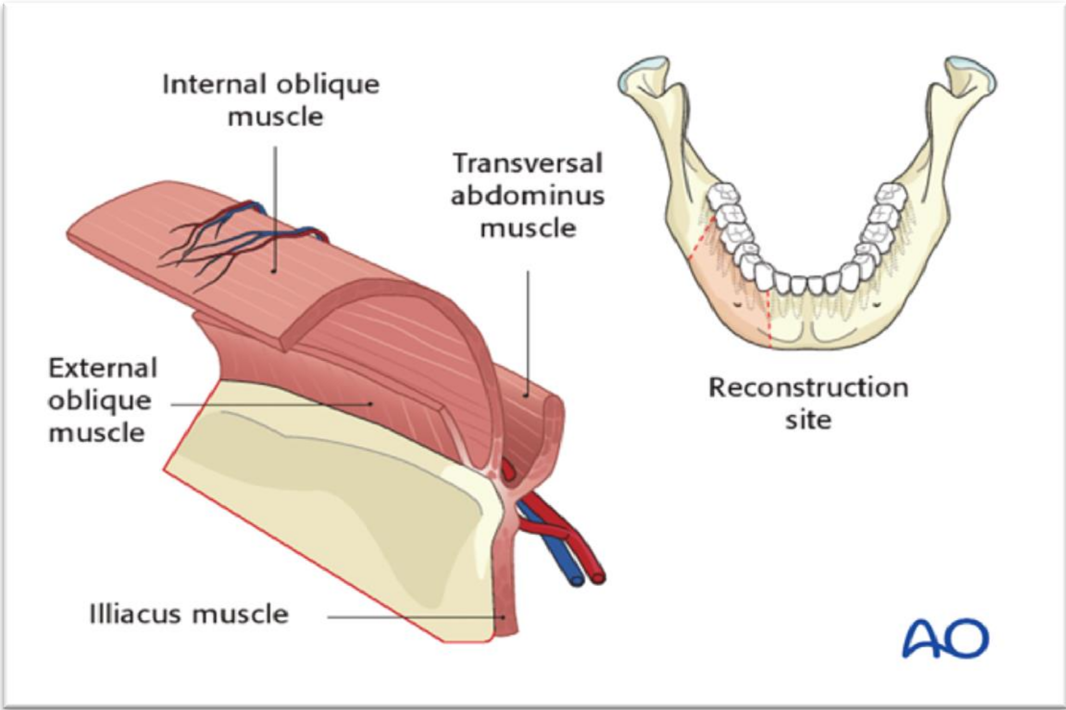

Figure 4: iliac crest flap for mandibular reconstruction

Therefore, many types of bone-graft substitutes have been searched and developed to eliminate and drawbacks of the autogenous graft.

1.3.Allograft bone substitutes Allograft bone is bone harvested from genetically non-identical members of the same species. Allograft is osteoconductive and osteointegrative and may exhibit an osteoinductive characteristic **(Simpson et al., 2007)**.

However, it has not osteogenic potential because it does not contain an osteogenic cell. Virtually any size or shape of graft needed may be supplied by contemporary bone banks. Allograft bone can be processed as mineralised or demineralised, fresh-frozen or freeze-dried bone forms **(Simpson et al., 2007)**.

The advantages of allograft bone upon the autograft are that it avoids the morbidity associated with donor-site complications of autograft transplantation and is readily available in the desired quantity and configuration. Furthermore, the use of the allograft bone affords considerable time saving during Surgery **(Simpson et al., 2007)**.

1.4.Xenograft Bone substitute Xenograft is a tissue harvested from one species and transplanted into a different species. Bovine, coralline and porcine are the three familiar sources of xenografts that are osteoconductive and readily available **(Rodella et al., 2011)**.

Bovine hydroxyapatite (Bio-Oss) is the most commonly researched and used xenogeneic graft.It has been used in dentistry for more than 20 years for implant encouragement **(Cordaro et al., 2008)**.

In general, xenograft bone has been used successfully in grafting procedures **(Block et al., 2002).**

The disadvantages with this graft include a host rejection immune response and risk of transmission of disease. To reduce the side-effects, the xenograft is treated rendering them sterile and totally biocompatible. However, bone xenograft still shows slow resorption **(Block et al., 2002).**

1.5.Alloplastic Bone Graft Substitutes Alloplasts are synthetic bone grafting materials that have been used mostly since their unlimited supply **(N.M. Al-Namnam, Soher Nagi Jayash,2019).**

Advantages They are biocompatible, osteoconductive and do not carry the risk of disease transmission. Concerning resorption, degradation of alloplasts depends on the physicochemical property, volume, physical environment of the grafted material, patient age, number of adjacent bony walls, and local vascularity for use as bone graft substitutes .The synthetic materials of interest are those that mimic the mineral phase of bone. They afford some structural support and prevent fibrous tissue ingrowth when facilitating creeping substitution by the host bone **(N.M. Al-Namnam, Soher Nagi Jayash, 2019).**

These include:

1.5.1.Calcium sulfate: Calcium sulfate (plaster of Paris, Gypsum) is considered the oldest synthetic bone graft substitute used in bone regeneration. The chemical reaction which occurs during the setting time of calcium sulfate leads to the change in its crystalline structures and thus unstable chemical properties. This inconsistency leads to rapid resorption, within 4-8 weeks, that exceeds the capacity of the bone regenerate process, potentially outstripping the rate of newly formed bone and leaving an unhealed bone defect. Because of its poor bioactivity, it cannot osseointegrate with host bone tissue at the early stage of therapy. Thus it is not very reliable clinically. However, it may still have a future role as a carrier until superseded with more reliable osteoinductive materials **(Middleton and Tipton, 2000).**

Furthermore, it is not used for socket grafting or implant site development as a stand-alone material because of its resorption rate **(Feuille et al., 2003)**.

1.5.2.Calcium phosphate: Calcium phosphate (Ca-P) ceramics have been used in dentistry since the 1980s **(Shastri et al., 2004)**.

They have the similar mineral composition of the bone. They consist mainly of hydroxyapatite (HA) or tricalcium phosphate (TCP) or HA/TCP in a different ratio to form a biphasic mixture (BCP). They are available in many different forms such as wedges, granules, blocks, pastes, and cement. They are widely used for bone substitution, repair, and augmentation and have a clinical acceptance in many areas of dentistry **(Salgado et al., 2012).**

Hydroxyapatite Porous hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$) is the most extensively bone substitute for treating periodontal defects. It has been marketed in different forms; solid or a dense non- resorbable, a porous, nonresorbable and a resorbable form. It is available in a variety of form from paste to rigid blocks. HA shows excellent biocompatibility with the human tissue, however, its applications are limited to coat and non-load-bearing areas due to its low mechanical properties. Its exhibits slow resorbability and brittleness, thus it is often combined with other materials for improved its function and accelerate its resorption. The osteoconductivity of synthetic hydroxyapatite is controversial. While some authors found promising results regarding scaffolding of these materials, others have opposite effects **(Wang et al., 2009)**.

1.5.3.Tricalcium phosphate (TCP) is a porous form of the calcium phosphate. It is partially resorbable and has osteoconductive properties. Moreover, it has gained clinical acceptance; unfortunately, its outcome in bone regeneration is not always predictable **(Al- Namnam et al., 2017)**.

The β-tricalcium phosphate is the most commonly used form of TCP; it's another available ceramic material that has been used in grafting alveolar ridge defects in the oral and maxillofacial site.It is present in two form, the granular wedges, and blocks. Some studies showed that β-tricalcium phosphate is a suitable scaffold **(Al-Namnam et al., 2016)**.

Conversely; others found that it is unreliable due to its early resorption during the bone healing process that leads to insufficient bone generation **(Coutinho et al., 2010)**.

1.5.4. Biphasic calcium phosphate (hydroxyapatite with tricalcium phosphate) (BCP) is available in different forms including granule, sticks, and cylinders. HA and β-TCP can be found in blocks with micropores and macropores. They are highly biocompatible, but they differ in the biologic response created at the recipient site. TCP-ceramic is faster resorbed at the implant site than HA which is more permanent (**Leor et al., 2005)**.

β-TCP has some advantages than HA when used as a filler, in that it is more rapidly reabsorbed since surface layers of TCP-ceramic enhance bonding with an adjacent bone that in turn stimulates the new bone formation and remodelling process within the area of the resorbed implant. Because of the different resorption rate between HA and β-TCP, researchers sometimes combined and modified them with other materials (e.g. HA/TCP combined with autogenous bone) to improve functionality and enhance the resorption process **(Shin et al., 2003)**.

In human, it has been reported that the application of β- TCP/HA graft after anterior cervical discectomy resulted in a high rate of fusion and patient satisfaction However, there is just a few reliable clinical data describing the resorption rates of BCP for socket grafting **(Shin et al., 2003)**.

1.5.6. Bioactive glasses: Bioactive glasses are non-porous and hard materials which consist of phosphorus, calcium, and silicon dioxide. By varying the proportions of its components, a wide range of forms from non-resorbable to resorbable material can be produced. The unique surface of bioactive glasses is the presence of HA bioactive layer that occurs through a biochemical transformation following implantation. It has been thought that this HA layer is responsible for bone cell attraction and bonding **(Seong et al., 2010)**.

The main clinical indication of bioactive glass is the filling of the bone cavity of the craniomaxillofacial region, which requires obliteration of the sinus.The material, however, is not suited for the reconstruction of continuity defects of jaw bones due to the lack of the required mechanical properties **(N.M. Al-Namnam, Soher Nagi Jayash,2019)**.

1.6.Use of Customized Polyetheretherketone (PEEK) Implants in the Reconstruction of Complex Maxillofacial Defects

Because of the disadvantages associated with commonly used materials, the search for the ideal implant continues. A potential candidate is polyetheretherketone (PEEK).It is a semicrystalline polyaromatic linear polymer that exhibits an excellent combination of strength, stiffness, durability, and environmental resistance. For these reasons, the material has been used for more than 20 years in the aerospace, automotive, and electrical industries. PEEK's biocompatibility has been established, and the material's following medical applications have followed **(Kim MM, Boahene KD, Byrne PJ,2009)**.

It was first developed in 1978 and has since been used in a wide range of applications owing to its excellent combination of high temperature performance, chemical resistance, fatigue resistance, lightweight, high yield strength, stiffness, and durability. Most prominently, PEEK has shown preliminary success in the treatment of cervical disk disease. Specifically, PEEK has served as a substitute for autogenous bone grafts and titanium cages in anterocervical fusion. PEEK coupled with a prefabrication process that can produce patient-specific implants (PSIs) may represent an ideal strategy in the reconstruction of challenging maxillofacial defects **(Ghantous Y, Nashef A, Mohanna A, Abu-El-Naaj I. 2020)**.

In addition, because PEEK implants are durable, workable, and biocompatible, the use of the implant may become more popular in the future.Various studies conducted with PEEK in reconstruction of complex maxillofacial defects and calvarial defects have shown excellent postoperative esthetic and functional results without any complications **(Thieringer, F.M.; Sharma, N.; Mootien, A.; Schumacher, R.; Honigmann, 2017)**.

Although a small number of PSI were performed in our department using the PEEK material, the authors believe that this material may be very useful for reconstruction of OMF defects, especially, at the non-sensitive sites that do not tolerate a directly applied pressure/load **(Cohen, D.J.; Cheng, A.; Kahn, A.; Aviram, M.; Whitehead, A.J.; Hyzy, S.L.; Clohessy, R.M.; Boyan, B.; Schwartz, Z, 2016)**.

Figure 5: Polyetheretherketone patient specfic implant

1.7.Virtual Surgical Planning in Oral and Maxillofacial Surgery

Selecting the appropriate imaging modality is an important initial step and depends on the advantages in spatial and contrast separate objects in a radiographic image (i.e., a nerve canal within the resolution. Spatial resolution is the ability for an image modality to differentiate between 2 mandible) whereas contrast resolution is the ability to differentiate image intensities between 2 areas {i.e., fat stranding vs normal adipose tissue} **(Allisy-Roberts P, Williams J. Farr's physics for medical imaging. New York: W.B. Saunders Company; 2007)**.

Computed tomography (CT) scanning has high spatial resolution, but is somewhat limited in contrast resolution. For this reason, CT scans are ideal for oral and maxillofacial cases because they often involve hard tissue interventions, such as surgery on the bones and teeth. Similarly, cone beam CT has many advantages when used in the appropriate surgical setting. Cone beam CT scans offer high spatial resolution with less radiation exposure compared with CT scans, but at the cost of poor contrast resolution **(Pauwels R, Beinsberger J, Stamatakis H, et al., 2012).**

For a detailed evaluation of soft tissue structures, MRIs have far superior contrast resolution when compared with CT scans **(Lin E, Alessio A., 2009)**.

As an additional method to improve the resolution of surface structures, 3-dimensional (3D) laser scanning is now used to provide the fine detail necessary to facilitate procedures where meticulous detail, such as the ridges and grooves of teeth, are necessary.

For example, the fabrication of occlusal splints used in orthognathic surgery can be created from data acquired from laser topography; in turn, traditional stone models are no longer necessary VSP provides the surgeon an opportunity to minimize the uncertainty associated with surgery **(Kau CH, Richmond S, Zhurov AI, et al., 2005)**.

The ability to visualize resection margins and to design reconstructive strategies is a significant benefit to management of facial trauma, craniofacial surgery, and pathology **(Herford AS, Miller M, Lauritano F, et al., 2017)**.

In the setting of maxillofacial trauma, VSP allows for the fabrication of custom implants. VSP is used extensively in the management of maxillofacial pathology for its ability to virtually visualize pathology and to provide guidance on the location of resection margins. The application of guided osteotomies is most beneficial in surgical resections of the midface and for large tumors that have deformed anatomic landmarks **(Chim H, Wetjen N, Mardini S., 2014)**.

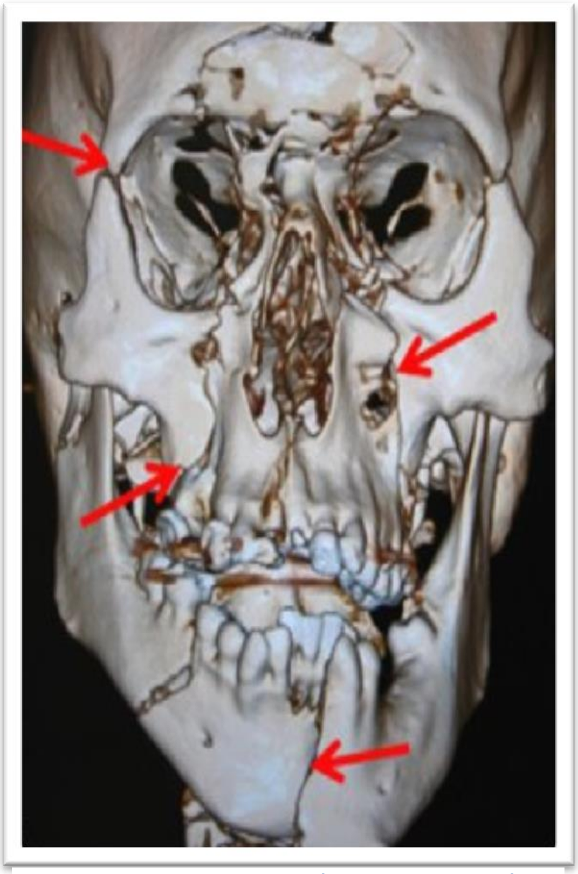

Figure 7:Examples of ct images(3D reconstruction)

Figure 6: 2D coronal cut

1.8.Three-Dimensional Technology Applications in Maxillofacial Reconstructive Surgery

Three-dimensional (3D) printing is a novel technique that has evolved over the past three decades and has the potential to revolutionize the field of reconstructive medicine in general **(Colaco, M.; Igel, D.A.; Atala, A., 2018).**

Since its first description by Hideo Kodama in 1981, 3D technology has matured and many more sophisticated different printers than the original machines currently exist, allowing for application in a range of fields including aerospace, engineering, consumer products, arts, food industry, education, manufacturing, and medicine. Three-dimensional printing is also defined as additive manufacturing (AM), and this technique uses metals, ceramics, and plastic material to produce three-dimensional (3D) objects for the usage in different disciplines, including medical application **(Ghantous Y, Nashef A, Mohanna A, Abu-El-Naaj I.,2020)**.

The AM process is defined by the International Organization for Standardization (ISO) and American Society for Testing and Materials (ASTM) as the "process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive and formative manufacturing methodologies" **(Rengier, F.; Mehndiratta, A.; Von Tengg-Kobligk, H.; Zechmann, C.M.; Unterhinninghofen, R.; Kauczor, H.U.; Giesel, F.L.. 2010)**.

The processes encompassed in AM are the 3D analog of the very common 2D digital printers; therefore, AM is also commonly referred to as 3D printing. AM has gained to many definitions over the last 30 years, such as direct digital manufacturing, additive layer manufacturing, additive fabrication, additive processes, free-formed fabrication, solid free-formed fabrication, rapid manufacturing, and rapid prototyping (**Gibson, I.; Rosen, D.; Stucker, B., 2015).**

Thus, AM is considered as the ideal technology for producing unique 3D objects that are manufactured in low volumes that are generally used for medical and dental applications **(Ghantous Y, Nashef A, Mohanna A, Abu-El-Naaj I., 2020)**.

1.8.1.Uses

3D printing helps in facial reconstruction surgeries. The implant for the surgery is shaped on 3D surgical model before the surgery, reducing trauma to the tissue and the operating time. Similarly, in craniomaxillofacial surgeries, 3D printed models are used for pre-bending of reconstruction titanium plates on a 3D model prior to skull resections, help us restore the correct position of remaining bones accurately and reducing the surgery time **(Holub B., 2018)**.

3D models are extremely accurate prototype models that help new surgeons ease into preoperative planning and improving postoperative esthetics and facial contour symmetry, for example, the reconstruction of maxilla, mandible and orbits. This helps to inspect anatomy preoperatively, practice different treatment modalities, and reduce surgery time and minimize errors **(Holub B., 2018)**.

It serve as surgical guides for surgical resections or osteotomies based on preoperative imaging to provide higher Patient Safety Indicators, which is even more important in metal implant surgeries. Surgical guides in cranio-maxillofacial surgery are also used for bone resections and free flap construction using a fibula free flap. 3D printed surgical guides are also used for accurate treatment planning for rib grafting and fixation in mandibular ramus deficiencies. 3D models are also used in orthognathic surgeries(Orthognathic surgery is a type of corrective surgery done to restore proper anatomy and functional relationship in patients with dentofacial skeletal anamolies). 3D models help achieve preplanned operations for performing accurate osteotomies and perfect positioning of unaligned jaw. Printing of cutting guides for osteotomies and 3D printed patient specific fixating plates for accurate positioning of jaws, greatly reduce mistakes made due to human error **(Gupta H, Bhateja S, Arora G. 2019)**.

3D printed intraoperative dental splints are used for accurate repositioning of jaw/midface with 3D preoperative planning in case of facial fractures.

3D printed models make for high-accuracy prostheses that enhance the aesthetic and psychological states of a patient suffering from poor aesthetics due to scarring, deformation or asymmetry. 3D printing is also used to make patient-specific implants (PSI), based on 3D imaging to provide perfectly fitting implants to restore proper anatomy, symmetry, relation and function. After mandibular resections and avulsion injuries, titanium implants, for load-bearing reconstruction, combined with autogenous bone grafts and PSI integrated with dental implants are used for dental arch and occlusion restoration **(Gupta H, Bhateja S, Arora G. 2019)**.

PEEK implants are used to restore zygomatico-orbital complex and mandibular angle deficiencies for trauma injuries, orbital wall defects and in syndromic patients **(Holub B., 2018)**.

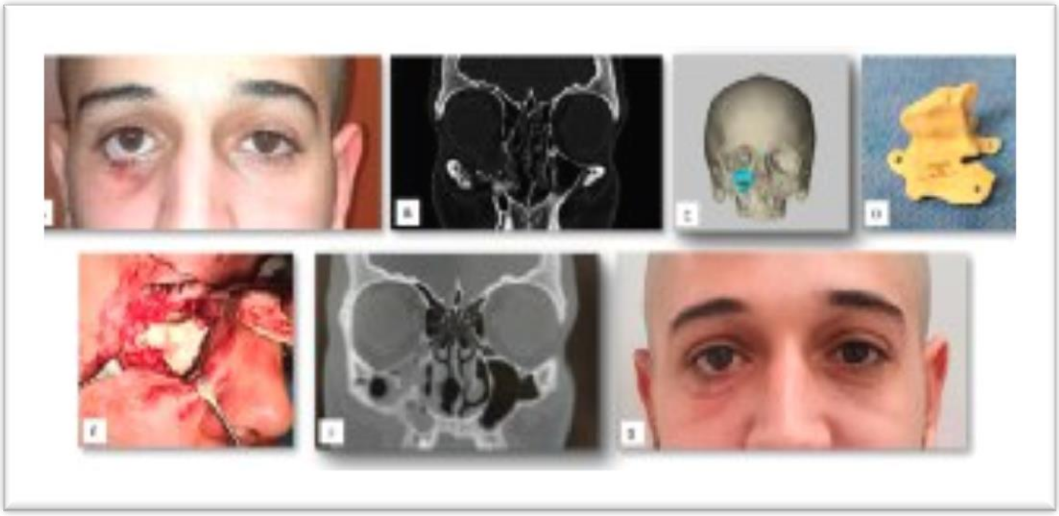

Figure 8:A) A clinical view shows significant right-sided enophthalmos, cicatricial ectropion (B) A preoperative coronal computed tomography (CT) scan shows the defect of the right infraorbital rim (C) Pre-operative 3D planning. (D) Individual custom reconstruction implant. (E) A post-operative coronal CT scan shows the position of the right infraorbital rim. (F) Postoperative implant position. Coronal CT scan shows the position of the right infraorbital rim.(G) Clinical view shows an accepted postoperative esthetic result.

1.8.2. Advantages and Limitations of 3D printing

Advantages

1)3D printing is used to manufacture complex objects in a short time with fine details and different materials.

2) Fabricating objects with 3D printing helps with a lot of waste reduction, as the unused material at the end can be reused again.

3) It is easy to print small movable parts of the final object.

4) Product designs can be easily shared over internet for printing, instead of having to transport the entire object.

5) Some objects are preferably printed as materials used in 3D printing are better in terms of strength and finishing details, then materials used in traditional procedures.

6) 3D printing reduces the possibility of human error.

7) 3D printing helps to reduce overall wastage of construction material resource, energy consumption and environmental pollution **(Alexandru Pîrjan & Dana-Mihaela Petroşanu, 2013).**

Limitations

1. 3D printing is a very expensive endeavor.
2. With the development of virtual treatment planning technology, usage of 3D printed models for treatment planning has lessened.
3. There are no parental controls to stop children from misusing it.
4. 3D printed objects can sometimes be of a lower quality than if they were traditionally manufactured, like lower functionality and resistance **(Gupta H, Bhateja S, Arora G. 2019)**.

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